"Case-Based Reasoning for Space Applications: Utilization of Prior Experience in Knowledge-Based Systems"

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Abstract

It is imperative in resource-sensitive and critical command and control applications to provide automated systems with the proper amount, organization, presentation, and utilization of expert knowledge. The goal of this paper will be to describe Case-Based Reasoning as a vehicle to establish knowledge-based systems, based on experiential reasoning, for possible space applications. This goal will be accomplished through an examination of reasoning based on prior experience in a sample domain, and also through a presentation of proposed space applications which could utilize Case-Based Reasoning techniques.

Introduction

Much research has been conducted with the purpose of understanding and formalizing the representation and use of experiences in problem solving [1, 2, 6, 7, 9, 10]. Case-Based Reasoning, CBR, is an area of study which examines the role of experiential reasoning in human problem solving. CBR techniques provide the ability to define, store, retrieve, and process previous experience. These techniques have been used in various domains, i.e. legal reasoning, structure survivability, diplomatic interaction, and others [1, 4, 5, 8, 10].

The majority of the efforts to date have been in the academic environment. Case-based reasoning is just beginning to emerge as a viable method for providing rich, knowledge-intensive foundations for the production and operation of expert systems. For example a new initiative, led by DARPA, is under way to develop CBR systems for the Defense Department.

There exists a need for the encapsulation of prior experiences for many forms of problem analysis and decision aids. Some general domains where prior situational experience provides human operators with valuable insight are:
- Multi-sensor fusion and interpretation,
- Feature extraction and modeling,
- Diagnostic action and monitor facilities,
- Command, control, and communications,
- Training by Example or Tutorial Assistance.

Case-Based Reasoning, CBR, can be utilized as a method for structuring appropriate domain knowledge and processing capabilities to provide experiential reasoning in knowledge-based systems and conventional systems. For purposes of this paper the basic concepts of CBR will be discussed along with a description of an example domain. The last portion of the paper will present a list of possible applications related to the space program.

Case-Based Reasoning and a Representation Framework

Case-Based Reasoning, CBR, has been used by experts in various fields to accomplish the generation, examination, and learning of situation-based actions, or problem solutions, which are based on a collection of previous cases of experience or hypothetical experiences. Dr. Edwina Rissland of the University of Massachusetts states: "Design is an excellent example of a domain where CBR techniques are used for complex problem solving, where new solutions are found through analogical transformations of past ones ..."

There are two basic types of CBR:
- Precedent-based CBR in which past cases are precedents which are interpreted to provide solutions, analyses, and explanations of present cases.
- Problem-solving CBR in which past cases are accessed to provide new approaches to present situations. Analyses and explanations are not provided as a product of the case-based reasoning process.

A Case-Based Reasoning System Structure

The following steps are appropriate as a guideline of the process for a case-based reasoning system [3, 6a].

A. Presentation to the system of a new situation in the domain of the case-based system.

B. Analysis of the new case to create the reference points for retrieval.
   - This may include a specific interface for the new case. Such as a forms interface.
      - A forms interface may provide the system with the capability to begin retrieval based on incomplete information.
      - The retrieval space may be reduced based on various attributes. As the form is filled out to describe the new situation, specific rules may apply to guide the user in defining the new situation. This guidance will also cause pruning of the amount of knowledge that the system will search through during runtime.

C. Locate and retrieve a potentially applicable case from long term memory.
   - Locate a suite of potentially applicable cases.
   - Provide a structure for a long term memory structure which will represent "worlds" of cases, or groupings, meta-sets of cases.

D. Determine which portion of the old case might be applicable to the present situation.
   - Determine which portion or portions of the individual cases may simulate or relate to the present situation.
   - Relate the combinations of portions to provide a relationship which can help solve the present problem.

E. Derive the targeted value for the current case through various interpretations and actions:
   - The role of the targeted portion of the previous case in the success or failure of the previously derived plan.
   - Choice between a previously-used inference method or the value.
   - Potential applicability of the above to the current case.
   - A "weave" technique will be needed to relate target locations from various cases.
   - Evaluate "real-world" constraints that are associated with previous case attributes for determining the "real-world" effects on the present situation.

F. Check the proposed value for consistency with the current case.
   - Further constraint checking based on "real-world" knowledge that is associated with the domain. (Common-sense checking)

G. Provide default inference techniques if no similar case is found or if the constraints associated with the reasoning about the new situation are not common-sense in nature
   - Results for the value(s) of the case can be computed by default inference techniques and updated in the case to provide a new experience for the system.

H. Update the representation of the current case.
   - Update any "ripple effects" which are caused through the determination of a value in the present case.

I. Establish the new case in the memory of the case-based system
   - Provide the proper links and definitions to encapsulate this knowledge and provide a learning experience for the computer-based system.

Ongoing Research in an Applicable Domain

The SURVER system, SURvivability/Vulnerability Analysis Through Experiential Reasoning, is being built for the Air Force Weapons Lab, AFWL. The system will provide pre-test predictions for the survivability/vulnerability, S/V, of buried structures in nuclear blast simulations [4]. Currently pre-test predictions are based on finite-element analysis of blast effects on structural and material models and interpretation of the results by experts. Through knowledge elicitation it was apparent that the experts base judgements on previous experience with similar and dissimilar situations, or cases. The prototype is being built following a case-based reasoning design which provides for the definition, storage, retrieval, and processing of previous experience and will provide for automated S/V analysis.

A case-base is being assembled which consists of actual test data and the experiential factors which went into the analysis and solutions to the previous situations. A goal of the effort is a more in-depth case-base for proper utilization of the capability of case-based reasoning. Hypothetical cases will be produced through simulations of test situations which include variances to the following attributes: structure dimensions, material models, and the blast description. These hypothetical cases require that actual expert analyses be included within the case.

Another important aspect of this case-based reasoning system is that the CBR approach will provide the system with the ability to learn about new situations. Learning is defined in our prototype as the storage of a new situation along with the solution or analysis that has been provided through reasoning on past cases. A new case can be stored, after expert confirmation, through the definition strategy developed in the prototype. Cases will be indexed through structure type, blast type, and materials model type.

The very important aspect of reminding, or retrieval, in a CBR system will be accomplished in the SURVER system through two distinct methods. The cases will be indexed according to their representative attributes and an intersection method for retrieval will be used to retrieve the cases which best fit the present situation. As a refinement to the set of initial cases retrieved the system will perform a generalization function to provide retrieval through matching on not only specifics but also generalizations of values. This method is referred to as hierarchical domain-space retrieval. In this method a match can be provided on a minimum of information about the new situation through pruning of the search space via hierarchical representation.

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The system is being developed following an object-oriented, frame-based approach on a Zenith-248 using the development system GoldWorks^{tm} from Gold Hill Computers.

Case-Based Reasoning and Space Applications

The following is an abbreviated list of possible applications of Case-Based Reasoning for the space domain. This list was developed through an examination of possible areas which depend on human experience for control and interaction [1a].

A. Satellite system and component survivability/vulnerability modeling and analysis
   - Fault diagnosis satellite, station, and ground-based subsystems

B. Communications support through knowledge-based operator support
   - Satellite control
   - Ground-based systems, positioning
   - Signal interpretation

C. Automation of prior astronaut experience in critical situations:
   - EVA's
   - Situation assessment
   - Attitude control
   - Diagnostics and Repair

D. Command and control functions
   - Both onboard and ground-based

E. Weather forecasting
   - Critical decisions for mission control
   - Feature extraction and analysis

F. Training
   - Tutorial assistance for C^3 applications
   - Ground support, etc.

G. Remote operations:
   - Decision processes for landers and robotic appendage control
   - Capture and retrieval operations
   - Space Station remote support facilities

H. Launch monitoring

I. Modeling and Simulation
   - Component design and testing
   - System and operations

Summary

It is apparent that knowledge and reasoning are products of expert experience. Case-Based Reasoning provides an appropriate representation strategy, methods for reminding or retrieval of prior experiences, and the techniques for manipulating and reasoning about prior cases. The SURVER project for AFWL is one example of the application of these techniques to real world problems and analyses. Similar systems can be built for the

space program to provide for the ever expanding needs for automation and integrity assurance.

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